

Miniature Mass Spectrometer with CCD Array Detector

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Objective:

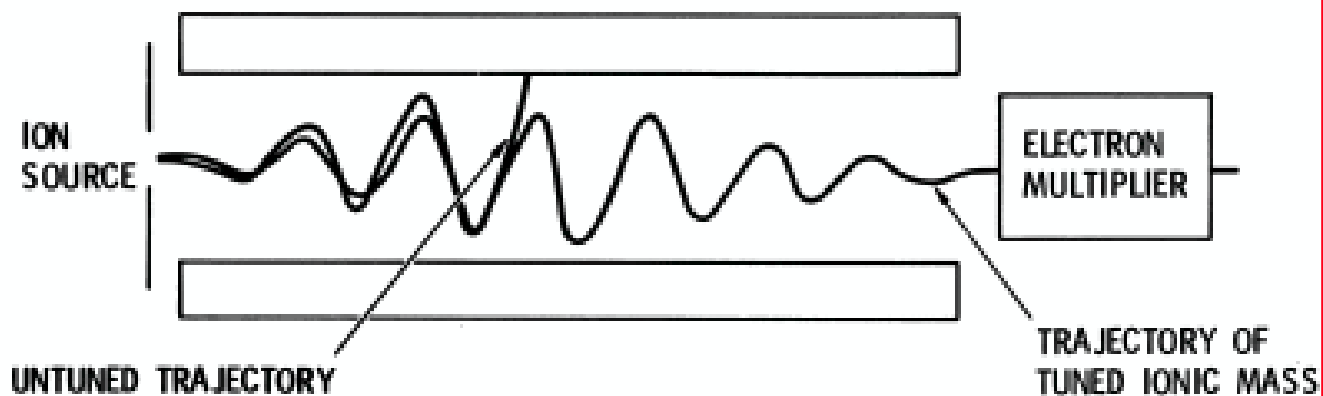
Development of a highly miniaturized, high performance mass spectrometer for determining the molecular, and **elemental/isotopic composition of species** present in planetary atmosphere, and surface/rock materials.

Applications:

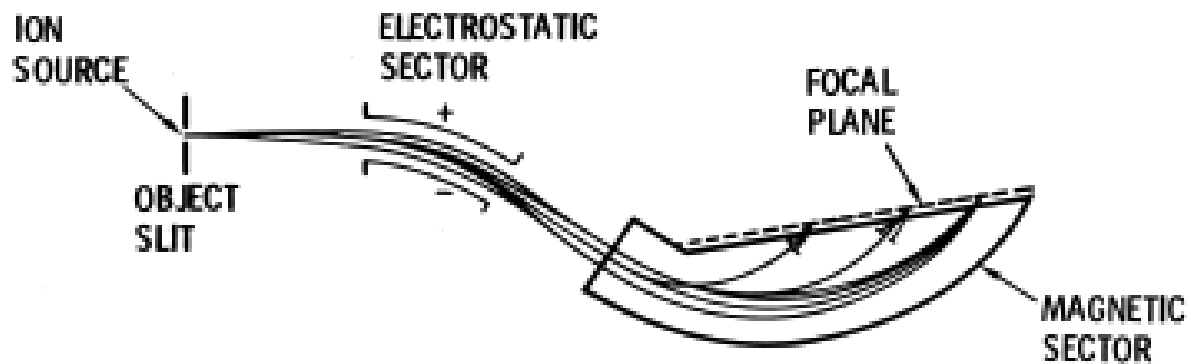
- **Mars follow-on missions, and missions to Outer planets**
- **Instrument to a number of NASA Applications**
(planetary rovers, planetary aerobots, entry probes and aerocapture entry systems)
- **Monitoring environments in Human Exploration and Planetary Habitats**
- **Environmental, and Industrial Applications**

Miniature Mass Spectrometer with CCD Array Detector

SCANNING QUADRUPOLE MASS SPECTROMETER



NON-SCANNING MASS SPECTROGRAPH



Miniature Mass Spectrometer with CCD Array Detector

MINIATURE MASS SPECTROMETER (MMS)

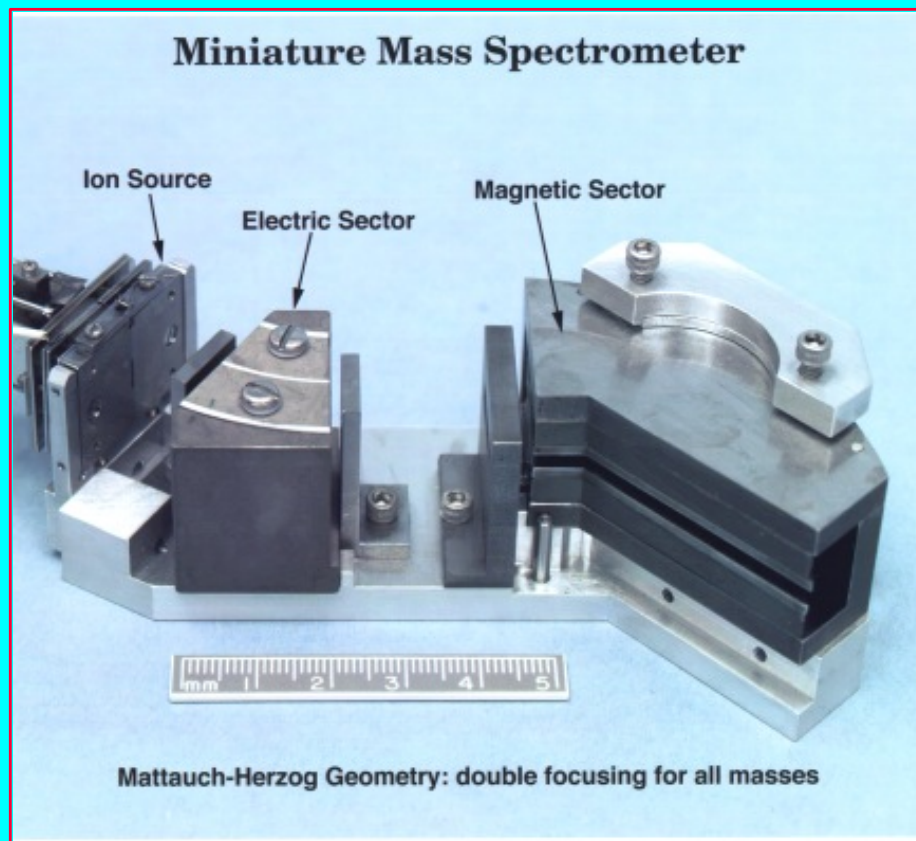
NONSCANNING/FOCAL PLANE GEOMETRY PROVIDES:

- *Simultaneous Measurement Of Different Mass Ions, AND, THEREFORE, 100 % DUTY CYCLE*
- *Relative Intensities not affected by changes in Ion source*
- *high Sensitivity/Detectivity*
- *fast Analysis*
- *narrow Peaks/ transient Samples*

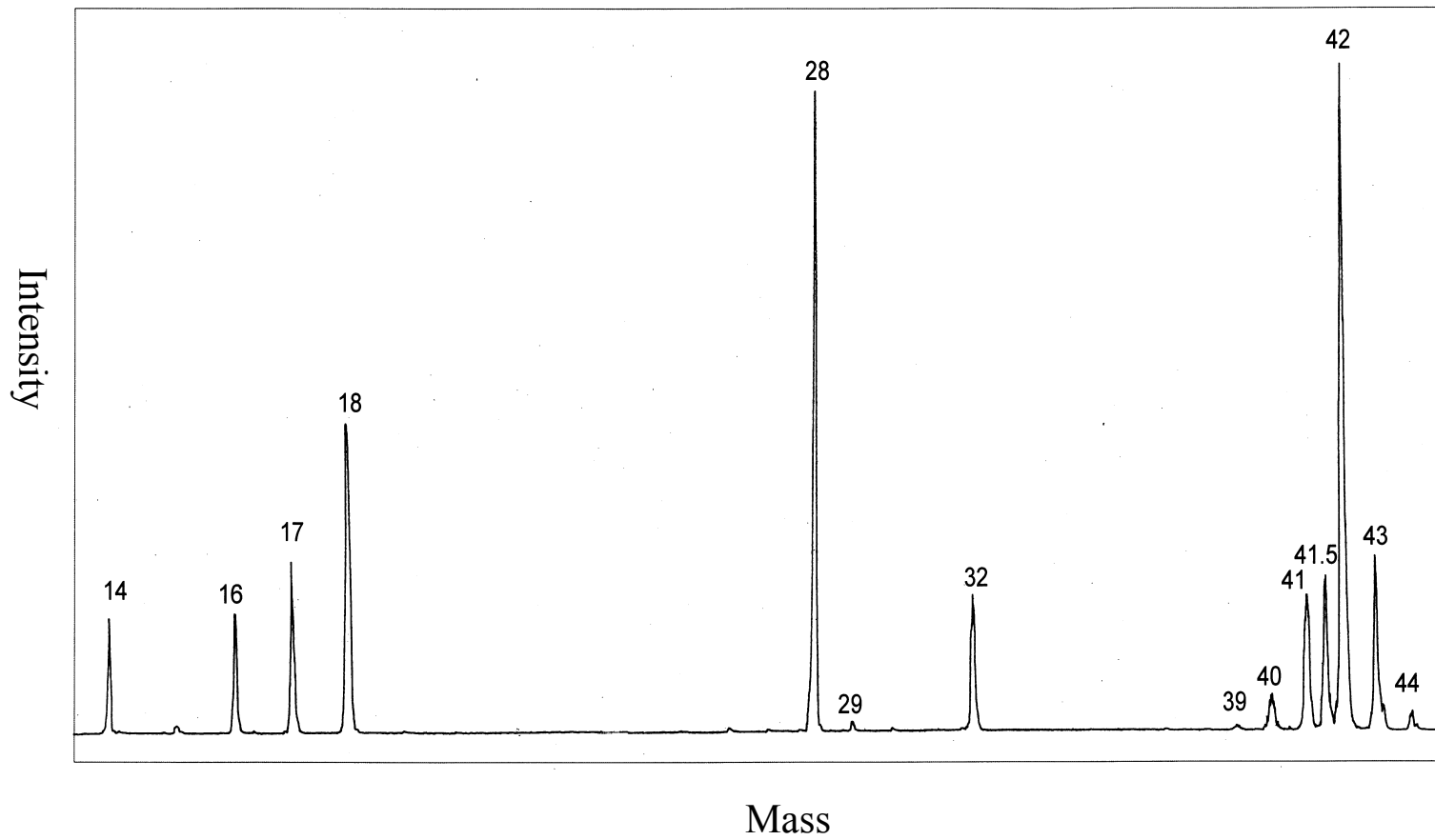
The above attributes make a nonscanning mass spectrometer uniquely suited for several applications. These include:

- **Isotope ratio measurements**
- **Combination with a microbore/micromachined GC columns**
- **Time-resolved measurements**
- **Laser-ablated material pulse measurements**
(e.g., Age-dating of rocks)
- **Signal Integration**

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Miniature Mass Spectrometer with CCD Array Detector

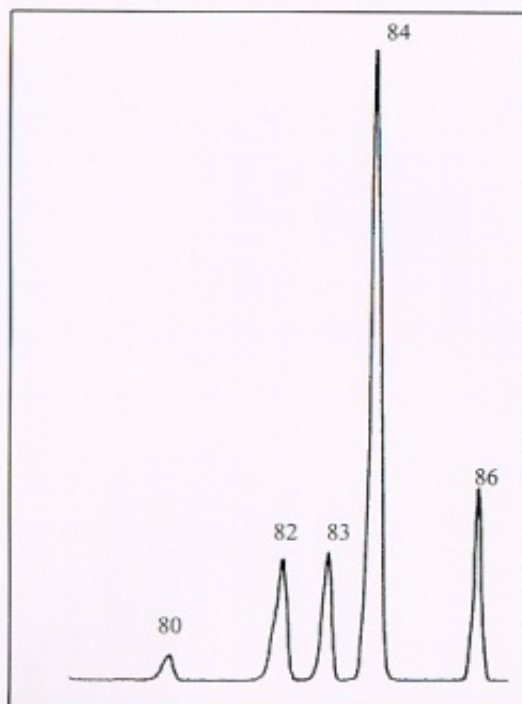


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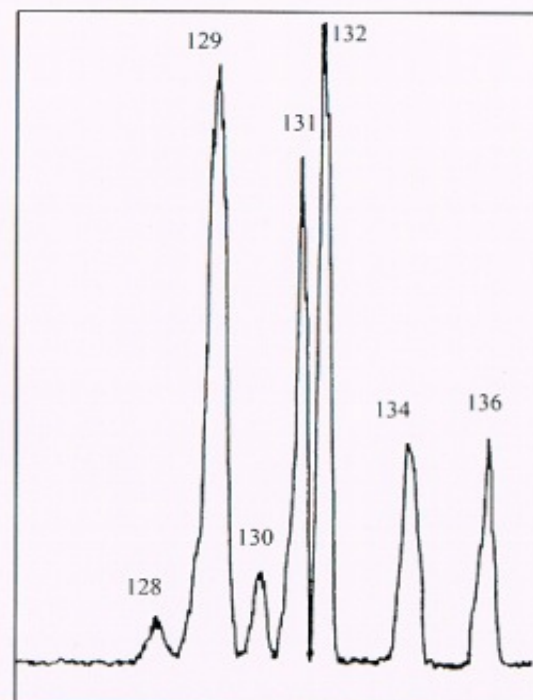
MINIATURE MASS SPECTROMETER

RECENT RESULTS:

Kr Isotopes



Xe Isotopes



Miniature Mass Spectrometer with CCD Array Detector

Desired features of the array detector include:

- *Direct ion detection (i.e., faraday cup mode of operation)*
- *High spatial resolution*
- *Sensitivity (preferably an inherent gain in charge domain)*
- *Low noise and dark current*

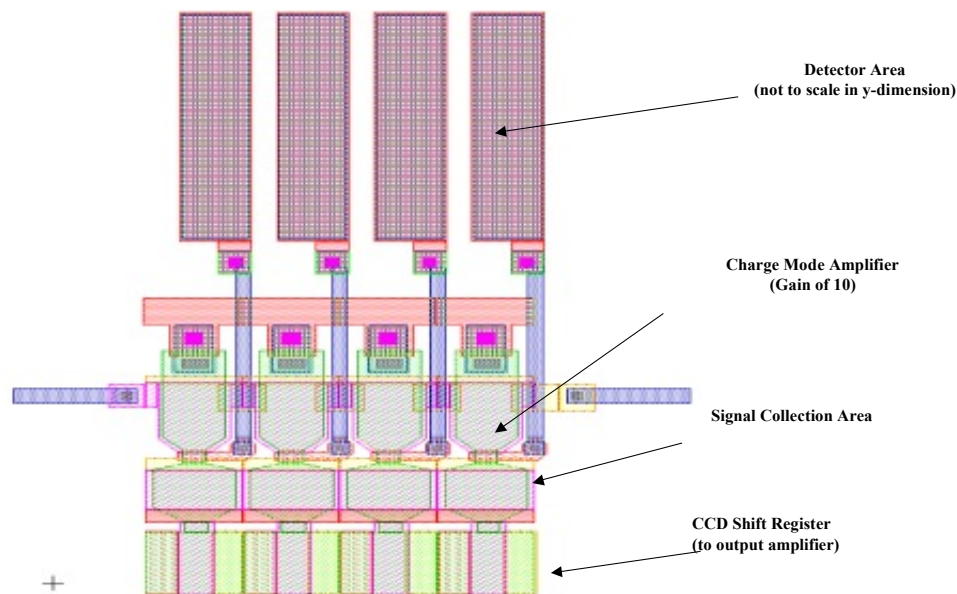
The CCD ion detector array developed in our laboratory meets the above requirements.

Other benefits of this approach are

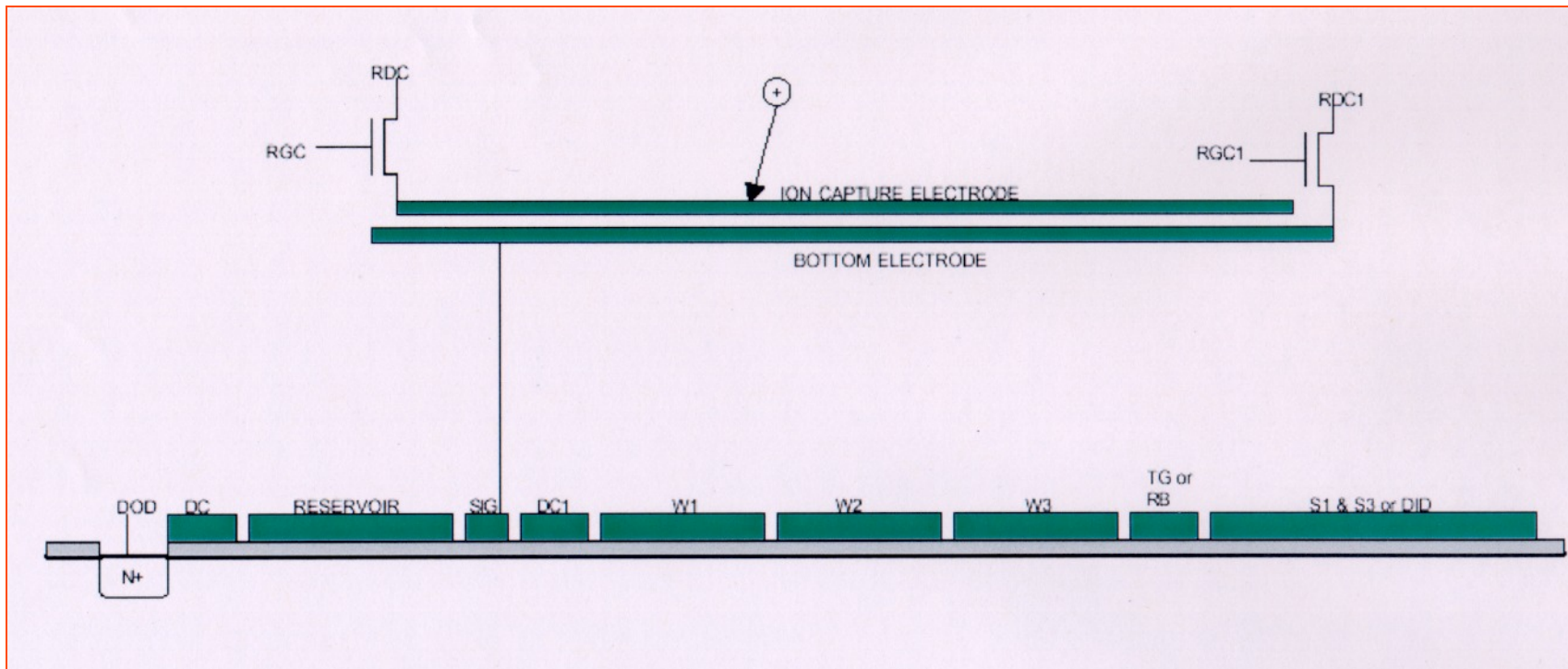
- *Electron Multiplication not needed (the trajectory of electrons are easily affected by the fringe magnetic field adversely affecting the analyzer performance)*
- *Effect of field penetration (MCP HV) into the Magnetic sector is eliminated*
- *Allows performance of MS at higher pressures.*

Miniature Mass Spectrometer with CCD Array Detector

Technology: The detector consists of a linear array of capacitive elements coupled to a CCD register by means of charge-mode input structure.

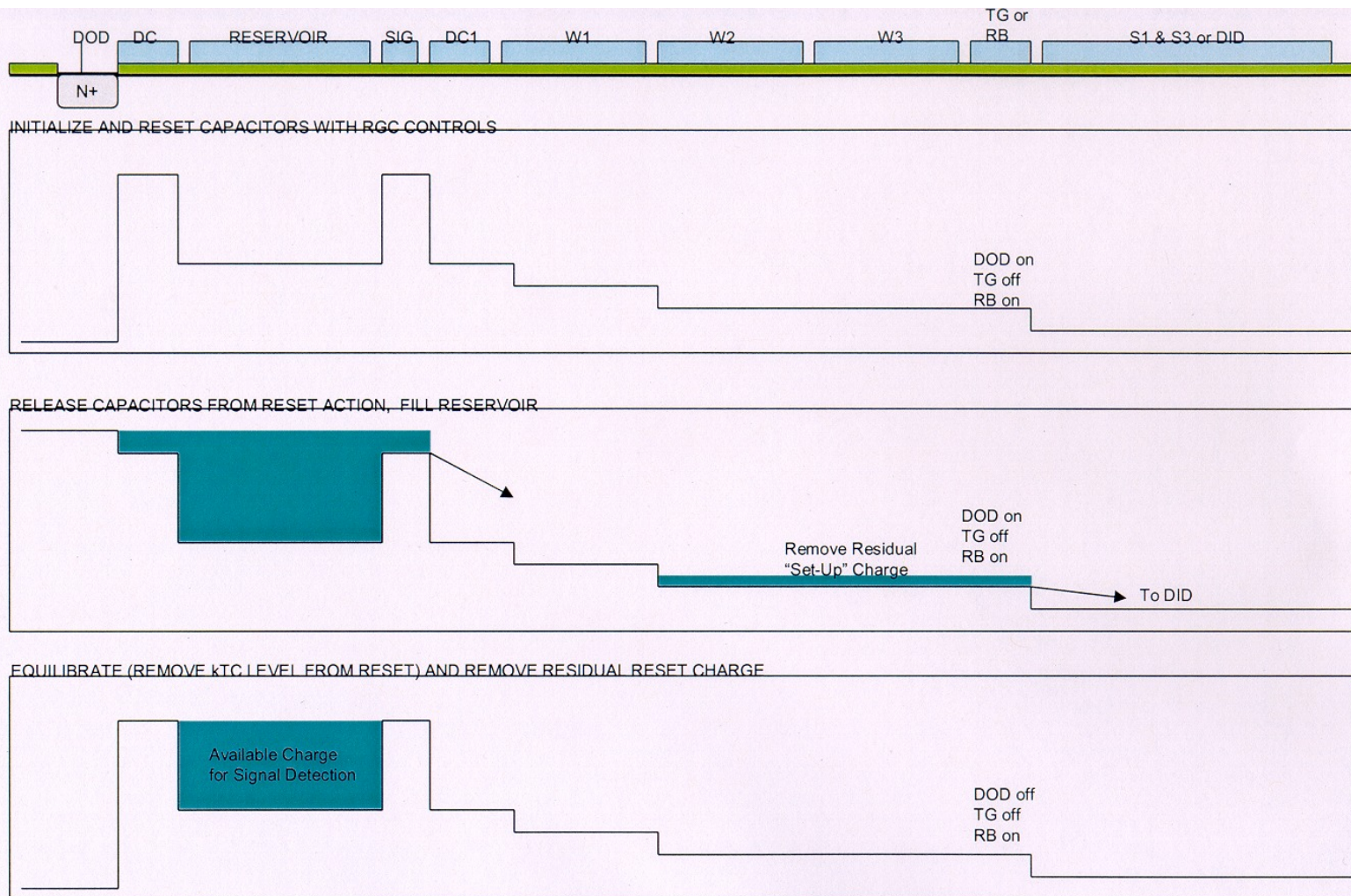


Miniature Mass Spectrometer with CCD Array Detector



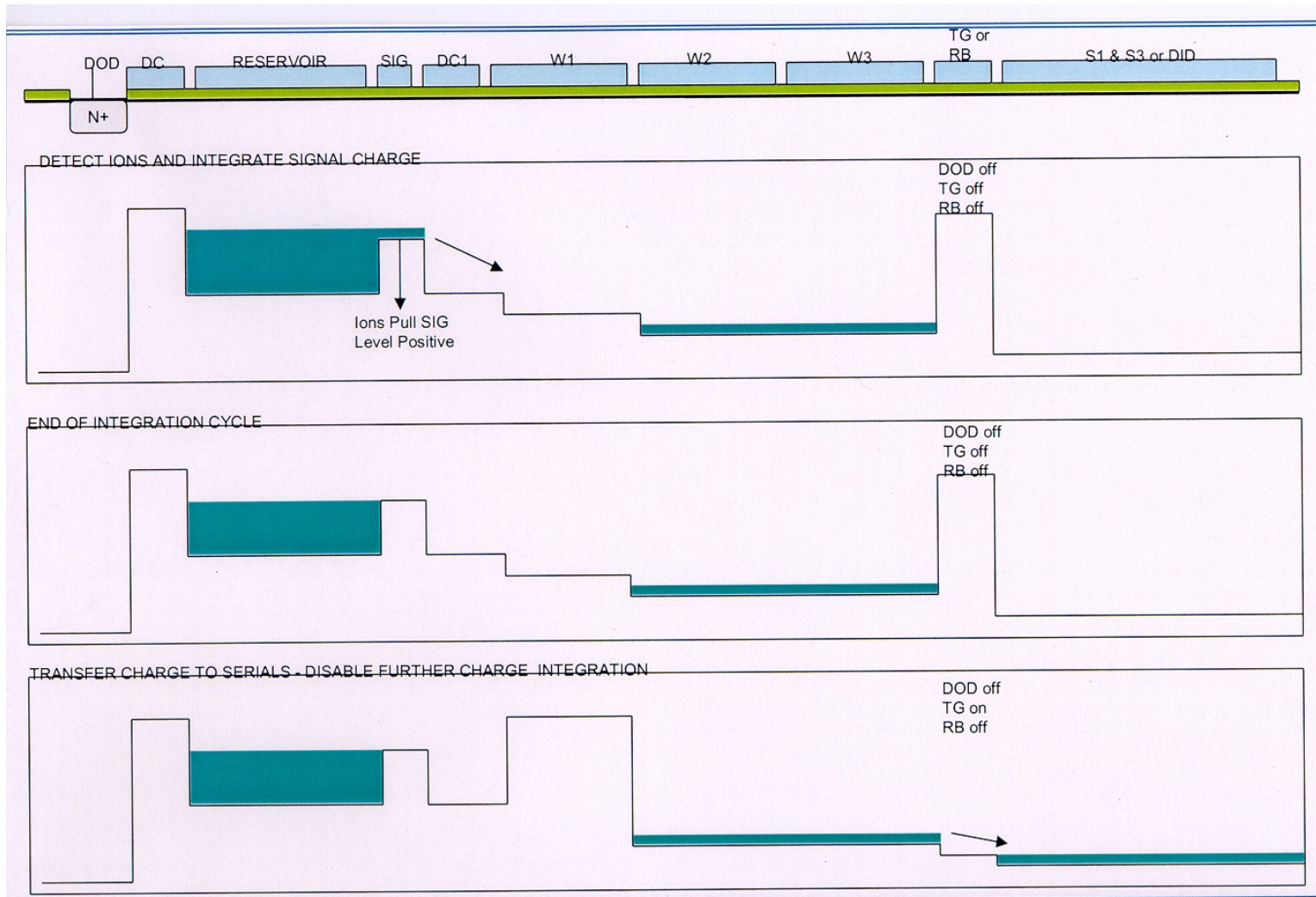
Unit cell of the Ion Detector

Miniature Mass Spectrometer with CCD Array Detector



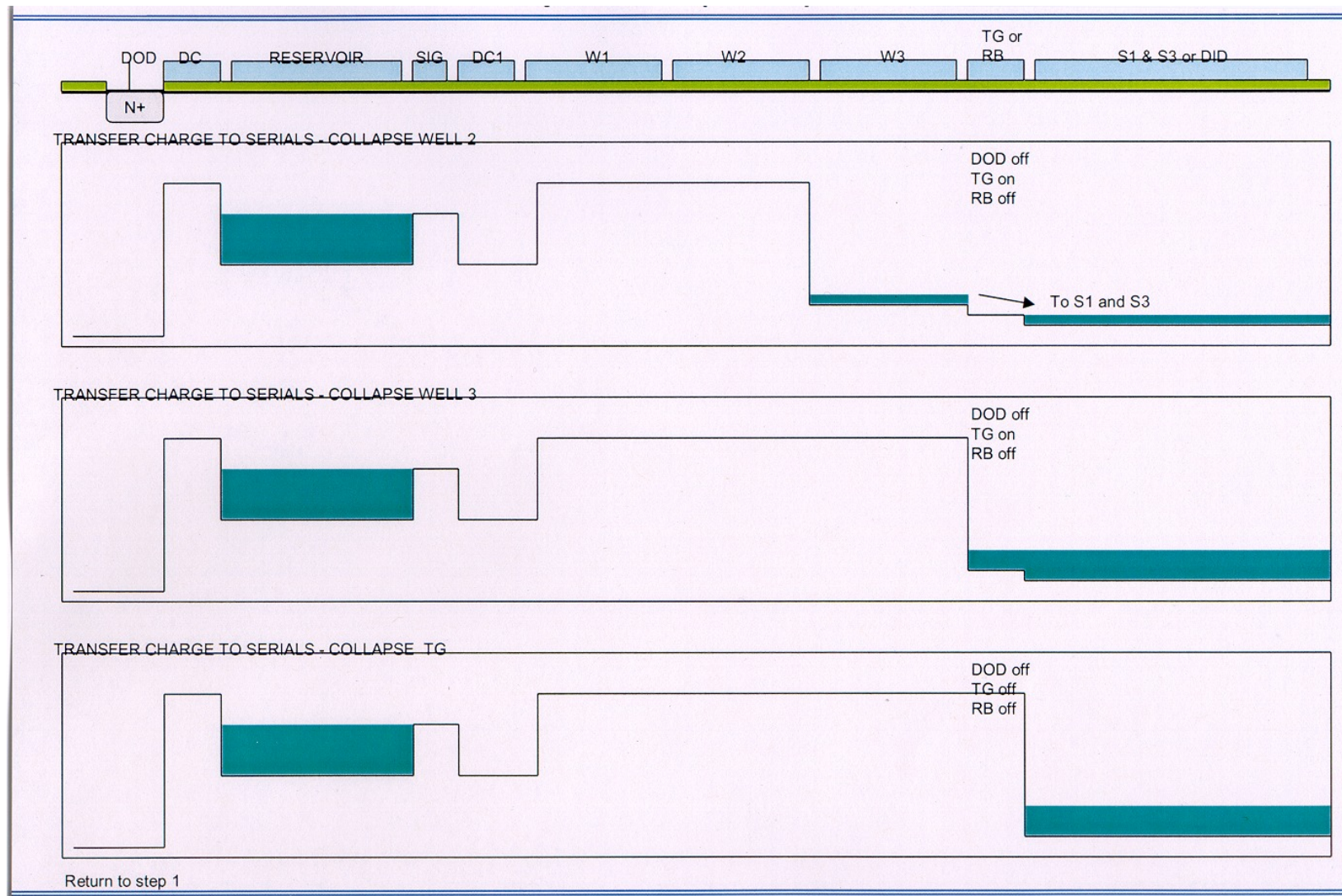
Operation of the Ion Detector Array

Miniature Mass Spectrometer with CCD Array Detector



Operation of the Ion Detector Array

Miniature Mass Spectrometer with CCD Array Detector

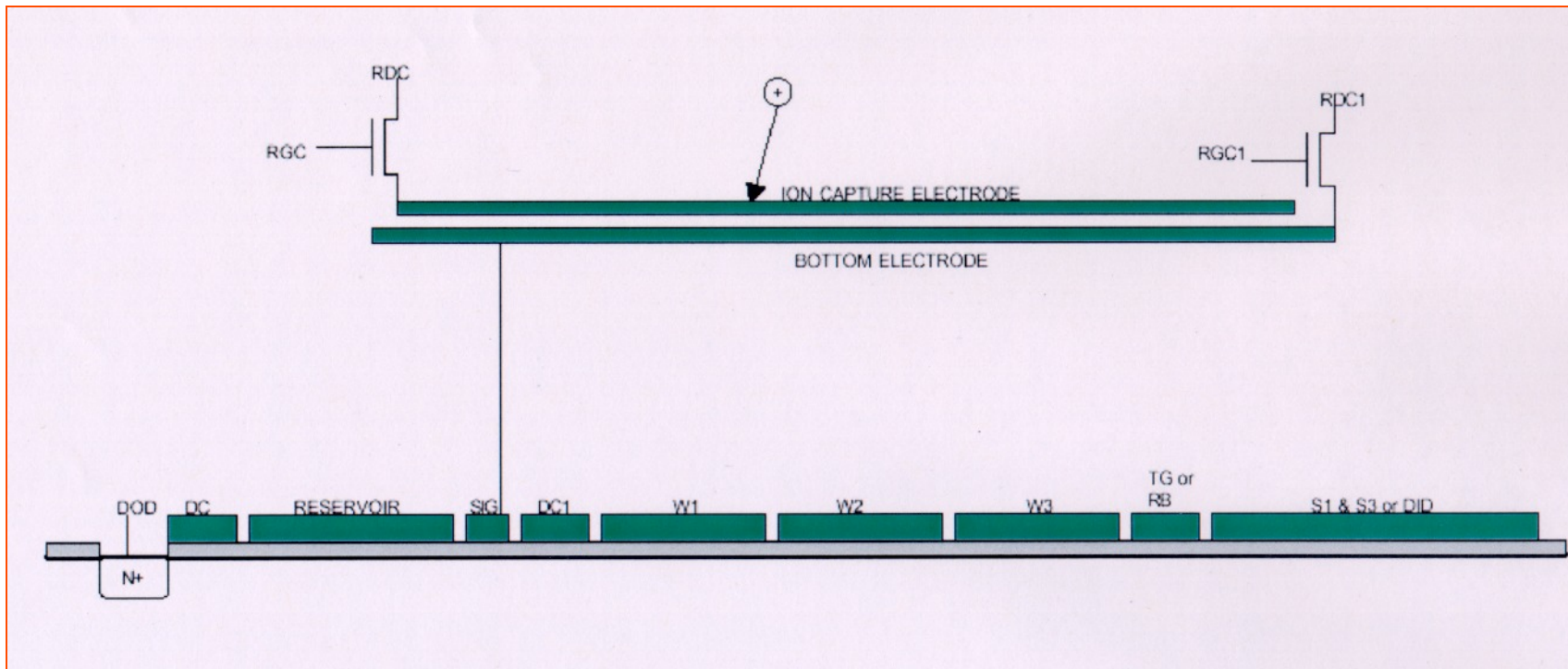


Miniature Mass Spectrometer with CCD Array Detector

Benefits of modified-CCD detector with Fill-and-Spill Input Structure:

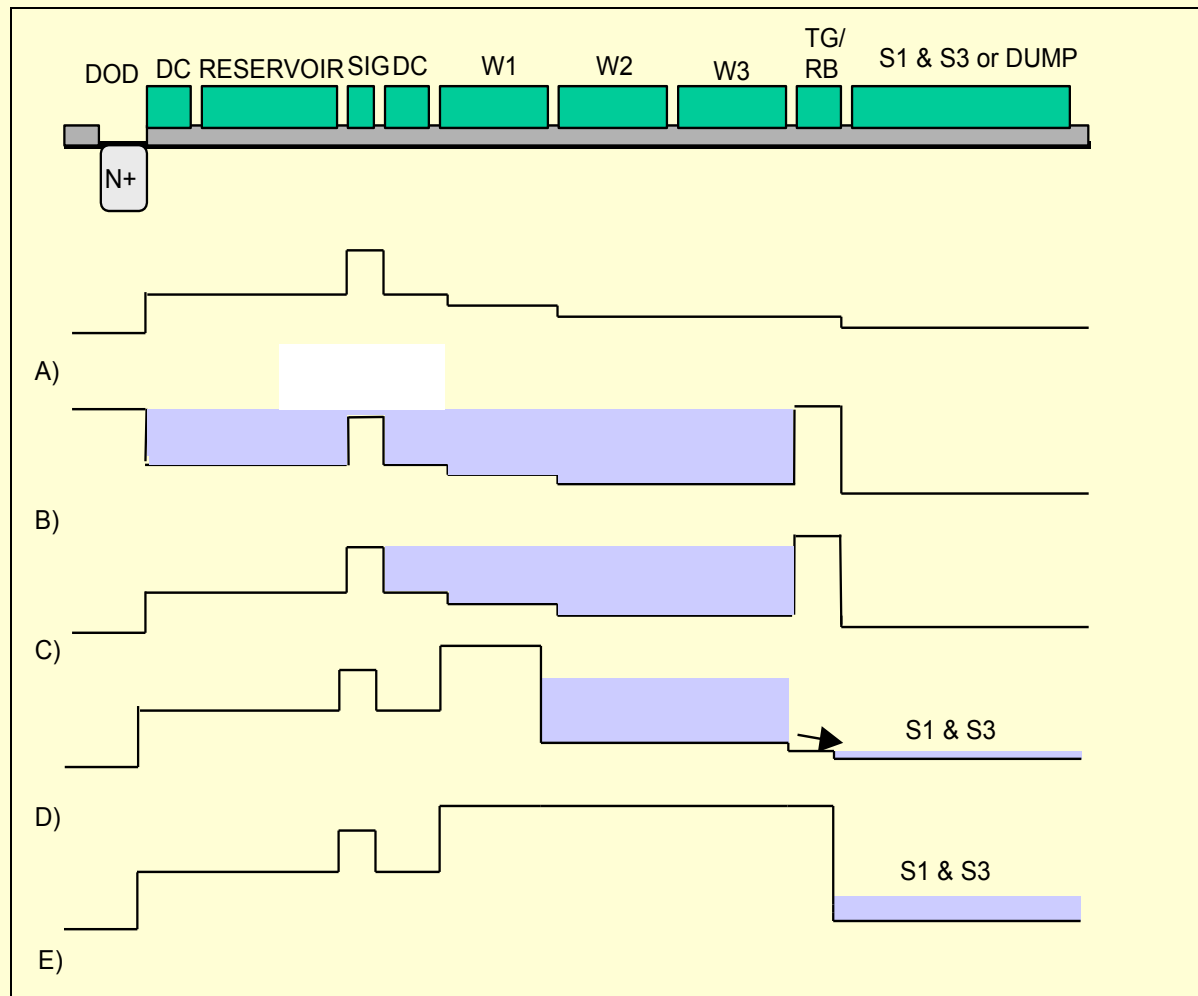
- Requires only one charge-to-voltage conversion
- Linearity of greater than 100 db
- Negligible offset level
- Gain in charge domain
- Eliminates potential offsets due to threshold voltage variations between gates during operation
- Removes kTC noise components that would otherwise be present as a result of filling a well with charge via a diode source.
- Provides larger dynamic range (*CCD typically supports operating voltage of 15 v*)

Miniature Mass Spectrometer with CCD Array Detector



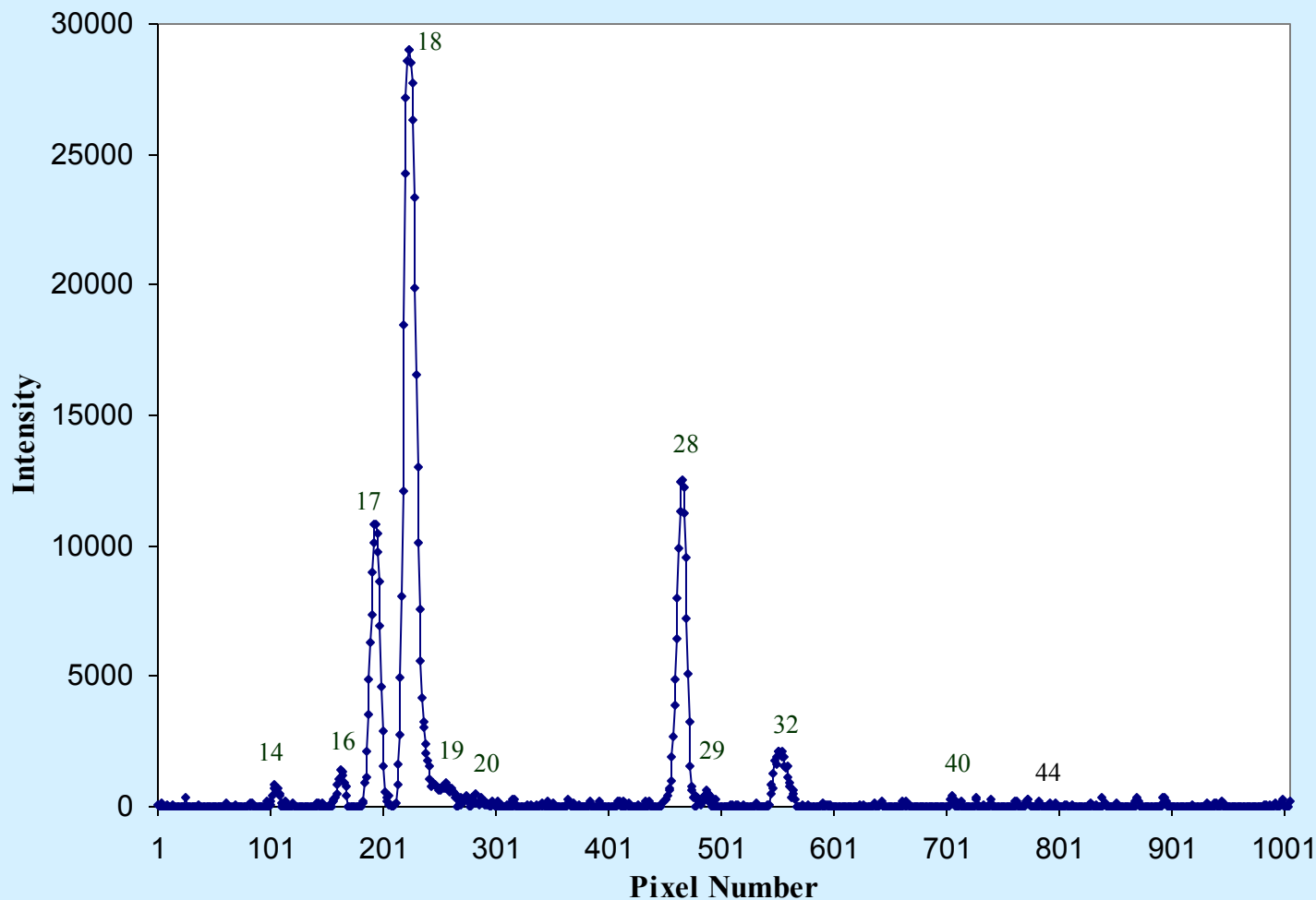
Unit cell of the Ion Detector

Miniature Mass Spectrometer with CCD Array Detector



Operating Sequence used for Ion Measurement

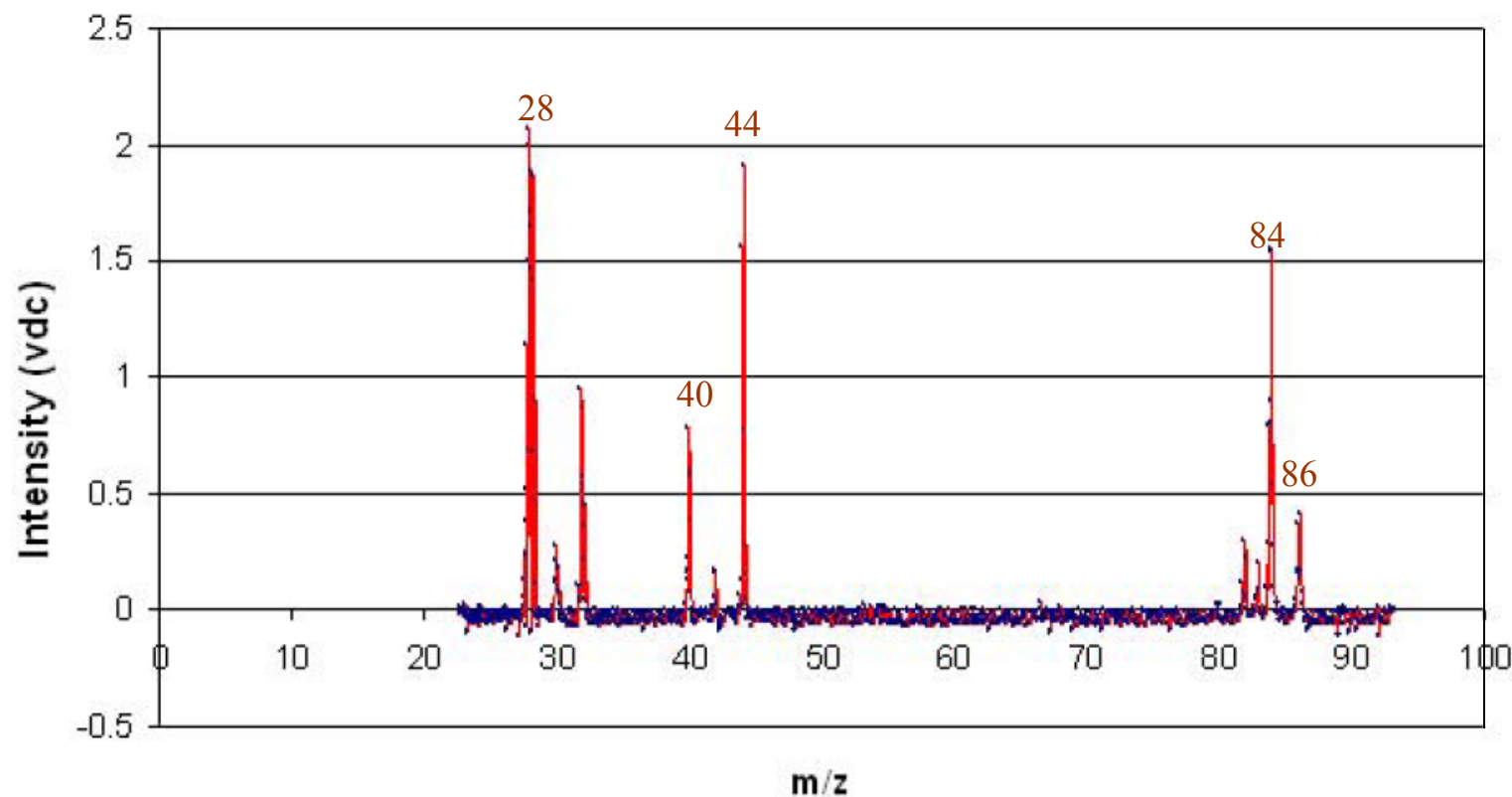
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Miniature Mass Spectrometer with CCD Array Detector

Fill-and-Spill Mode made operational *(in collaboration with the industrial partner OI analytical, Inc.)*

Spectrum of Air, Ar, CO₂ and Kr



Miniature Mass Spectrometer with CCD Array Detector

Performance of MMS

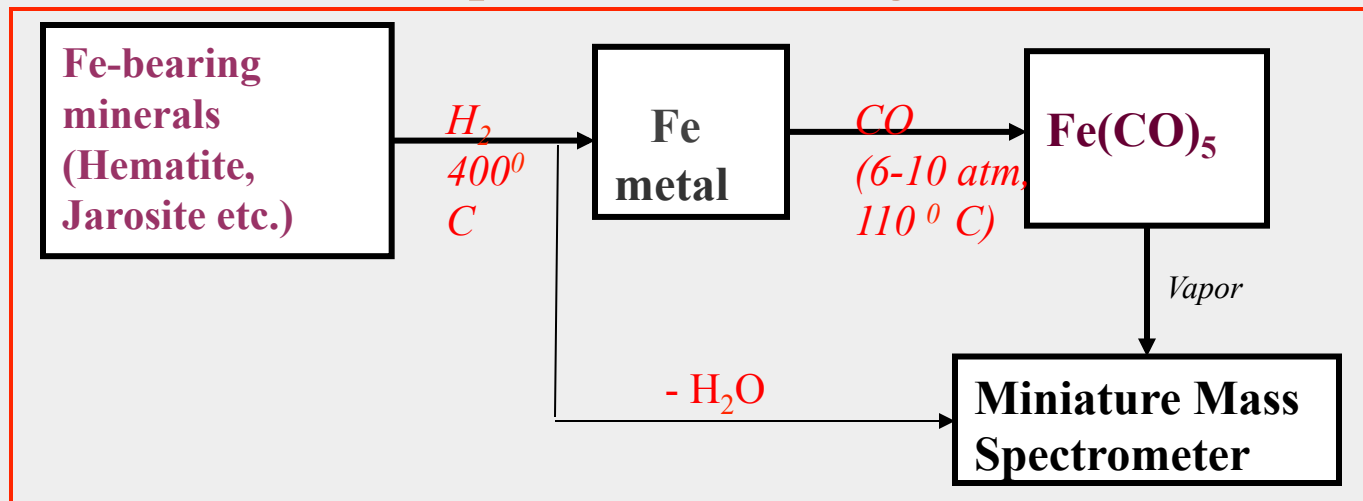
Weight (MMS)	1-1.2 Kg (Includes Power Supply and Pump)
Power (MMS)	2-4 W (operational), mW (standby)
MMS dimensions	10 cm x 5 cm x 5cm
Ion source	Thermionic
Mass range	2 - 200 u
Sensitivity	5-10 ions
Resolution	~312
Isotope ratio measurement	High reproducibility and precision
Compatibility with microbore GC	Uniquely suited because of 100 % duty cycle
Dynamic range	$10^4 - 10^5$

Current Work:

- Further CCD detector development
- Measurement of Fe and O isotopes in Fe-bearing minerals (ASTID task)
- Chemical and Isotopic Analysis of Laser-ablated Neutrals (PIDDP task)

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Fe and O isotopes in Fe-bearing minerals:



Advantages of the Methodology:

- Involves only Gas-Solid reactions (no wet chemistry)
- reactions controlled by Temperature and Pressure
- $Fe(CO)_5$ has high vapor pressure facilitating sample introduction and mass spectral measurement
- no isotopic fractionation in the reaction steps (*Talanta, 2006*)
- amenable for space applications (mms, internal calibration)

Science Significance

Isotopic composition of Fe in minerals will provide

- *evidence of the presence of Water (their hydrological cycle)*
- *paleoenvironmental conditions for the formation of the mineral*
- *their possible biological origin*

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Chemical and Isotopic Analysis of Laser-ablated Neutrals

Table I: Ionization Efficiency in Laser Ablation

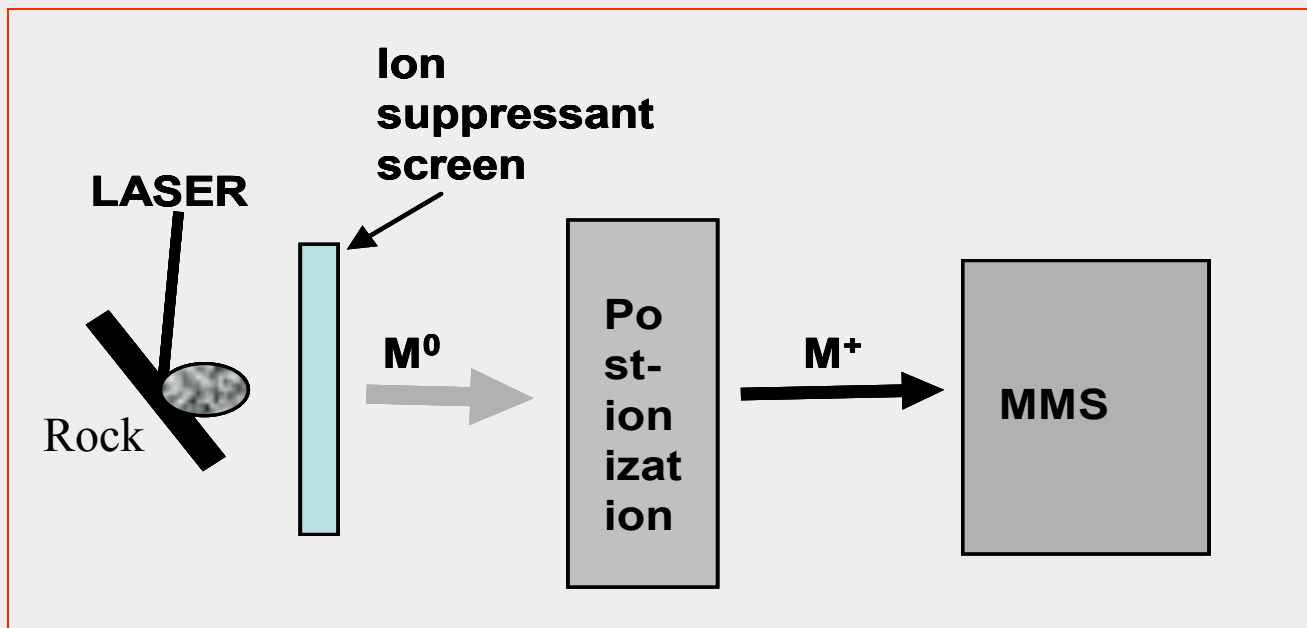
<i>Laser Energy (J)</i>	<i>Atoms eroded per laser shot</i>	<i>Ions created per laser shot</i>	<i>Ions created per atom eroded</i>
0.2	$\sim 10^{17}$	5×10^{12} to 2×10^{14}	3×10^{-3} to 10^{-5}
0.003 to 1	3×10^{13}	6×10^{11} to 10^{12}	3×10^{-2}
0.005 to 0.01	2×10^{14} to 5×10^{14}	2×10^{11}	4×10^{-4}
0.85	10^{17}	3×10^{13} to 3×10^{14}	3×10^{-3} to 5×10^{-5}
4	8×10^{17}	6×10^{12}	8×10^{-6}

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Table II: Comparison of the Efficiency of Measurement

Secondary Ion Pulse Width	Width of the ion pulse generated after post ionization of the neutrals produced by the laser ablation = 100 – 1000 μ s
Time-of-Flight Mass Spectrometer	Low duty cycle, Assuming ion extraction pulse of 10ns, the duty cycle for sample ion measurement is 10^{-4} - 10^{-5} per flight (20 μ s)
Quadrupole MS/ Magnetic Sector (scanning)	Not Suitable, complete mass scan during the short existence of the ion pulse in the source region is not feasible
Focal Plane MMS (nonscanning)	Uniquely suited, Efficient utilization of the entire signal pulse is enabled by 100 % duty cycle.

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Science Contribution: Chemical and Isotopic composition of rocks and soil samples on extraterrestrial bodies will provide an enormous range of information for these bodies, namely;

- *geological history, internal and external processes that shaped their evolution,*
- *age of rocks*
- *signature of extinct and/or extant life*

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Summary:

A new miniature mass spectrometer has been developed that possesses

- *focal plane geometry*
- *direct ion measurement with an array detector*
- *unique enabling measurement capability for chemical and isotopic analysis, and for combination with microbore column GC.*

Miniature Mass Spectrometer with CCD Array Detector

Collaborators:

1. Brian Beard & Clark Johnson
(University of Wisconsin, Madison)
2. Paul Braterman
(University of North Texas, Denton)
3. Mark Wadsworth
(Tangent Technologies, Monrovia, CA)
4. OI Analytical, Inc.
(Pelham, AL)

Miniature Mass Spectrometer with CCD Array Detector

Iron Carbonyl Spectrum with CCD array Detector

